



Calhoun: The NPS Institutional Archive
DSpace Repository

Theses and Dissertations

1. Thesis and Dissertation Collection, all items

1992-09

A Naval Shipyard optimal drydock loading and capacity utilization model

Brown, Richard A.

Monterey, California. Naval Postgraduate School

<http://hdl.handle.net/10945/38569>

This publication is a work of the U.S. Government as defined in Title 17, United States Code, Section 101. Copyright protection is not available for this work in the United States.

Downloaded from NPS Archive: Calhoun



Calhoun is the Naval Postgraduate School's public access digital repository for research materials and institutional publications created by the NPS community. Calhoun is named for Professor of Mathematics Guy K. Calhoun, NPS's first appointed -- and published -- scholarly author.

Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943

<http://www.nps.edu/library>

2

NAVAL POSTGRADUATE SCHOOL Monterey, California

AD-A257 322



DTIC
ELECTE
NOV 23 1992
S C D

THESIS

A NAVAL SHIPYARD OPTIMAL DRYDOCK LOADING
AND
CAPACITY UTILIZATION MODEL

by

Richard A. Brown

September 1992

Thesis Advisor:

Richard E. Rosenthal

Approved for public release; distribution is unlimited.

92-29893



Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited		
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE					
4. PERFORMING ORGANIZATION REPORT NUMBER(S)			5. MONITORING ORGANIZATION REPORT NUMBER(S)		
6a. NAME OF PERFORMING ORGANIZATION Naval Postgraduate School	6b. OFFICE SYMBOL OR	7a. NAME OF MONITORING ORGANIZATION			
6c. ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000		7b. ADDRESS (City, State, and ZIP Code)			
8a. NAME OF FUNDING/SPONSORING ORGANIZATION	8b. OFFICE SYMBOL	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER			
8c. ADDRESS (City, State, and ZIP Code)		10. SOURCE OF FUNDING NUMBERS			
		PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
11. TITLE (Including Security Classification) A NAVAL SHIPYARD OPTIMAL DRYDOCK LOADING AND CAPACITY UTILIZATION MODEL					
12 PERSONAL AUTHOR(S) Richard A. Brown					
13 TYPE OF REPORT Master's thesis	13b. TIME COVERED FROM TO	14. DATE OF REPORT (Year, Month, Day) 1992, SEPTEMBER		15. Page Count 66	
16. SUPPLEMENTAL NOTATION The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Naval Shipyard Drydocks, Drydock Loading, Optimal Drydock Loading, Drydock Capacity Utilization		
19. ABSTRACT (Continue on reverse if necessary and identify by block number)					
<i>The Naval Shipyard Optimal Drydock Loading and Capacity Utilization Model</i> presented in this thesis is a tool to optimally load the Naval Shipyard's drydocks. The problem is constrained by the length, type and timing of each ship's required maintenance; current and projected capability of existing drydocks; current load of the drydocks; and the requirements to perform maintenance on the drydocks. Prior to this model, the Navy used a suboptimal, manual procedure that took one to two weeks to perform. This inefficiency became critical when an Assistant Secretary of the Navy requested a drydock capacity utilization study, requiring optimal loadings under numerous scenarios. An optimization model which lacks limiting assumptions, allows easy modification of input data and is capable of quick analysis of drydock loading scenarios was developed and executed fast enough to provide timely answers. It is implemented via the <i>General Algebraic Modeling System (GAMS)</i>. Data management and interface with the GAMS software is controlled via the <i>Naval Shipyard Drydock Loading and Capacity Utilization Program</i> (a stand-alone program written in Microsoft QBasic).					
20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC			1a. REPORT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL Richard E. Rosenthal			22b. TELEPHONE (Include Area Code) (408)646-2795	22c. OFFICE SYMBOL OR/RI	

Approved for public release; distribution is unlimited.

A NAVAL SHIPYARD OPTIMAL DRYDOCK LOADING
AND
CAPACITY UTILIZATION MODEL

by

Richard A. Brown
Lieutenant, United States Navy
B.S., United States Naval Academy, 1985

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1992

Author:

Richard A. Brown

Approved by:

Richard E. Rosenthal, Advisor

Eric S. Theise, Second Reader

Peter Purdue, Chairman
Department of Operations Research

ABSTRACT

The Naval Shipyard Optimal Drydock Loading and Capacity Utilization Model presented in this thesis is a tool to optimally load the Naval Shipyard's drydocks. The problem is constrained by the length, type and timing of each ship's required maintenance; current and projected capabilities of existing drydocks; current load of the drydocks; and the requirement to perform maintenance on the drydocks. Prior to this model, the Navy used a suboptimal, manual procedure that took one to two weeks to perform. This inefficiency became critical when an Assistant Secretary of the Navy requested a drydock capacity utilization study, requiring optimal loadings under numerous scenarios. An optimization model which lacks limiting assumptions, allows easy modification of input data and is capable of quick analysis of drydock loading scenarios was developed and executed fast enough to provide timely answers. It is implemented via the *General Algebraic Modeling System (GAMS)*. Data management and interface with the GAMS software is controlled via the *Naval Shipyard Drydock Loading and Capacity Utilization Program* (a stand-alone program written in Microsoft QBasic).

DTIC QUALITY INSPECTED 4

Accession For	
NTIS	☒
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

TABLE OF CONTENTS

I. INTRODUCTION	1
A. THE NAVAL SHIPYARD	1
B. THESIS MOTIVATION: FUTURE SHIPYARD REQUIREMENTS .	2
C. MODEL DESCRIPTION	3
II. MODEL FORMULATION	5
A. CONSTRAINTS OF A DRYDOCK LOADING PLAN	5
1. Ship Schedules	6
2. Dock Capabilities	6
3. Current Load	7
4. Drydock Maintenance	7
B. INDICES	7
C. PARAMETERS	8
D. VARIABLES	8
E. FORMULATION	9
1. Objective Function	9
2. Dock Loading Limitations	10
3. Ship Assignment	12

III. MODEL ENHANCEMENT: RESOLVING SCHEDULE CONFLICTS . . .	13
A. RELAXATION OF LOADING CONSTRAINT	13
B. OPTIMIZATION OPTIONS	15
1. Additional Scalars	15
2. Additional Parameters	15
3. Additional Variables	15
C. ENHANCED MODEL FORMULATION	16
1. Objective Function	16
2. Dock Loading Limitations	17
3. Ship Assignment	17
4. Non-consecutive Overlaps	17
IV. PRE-OPTIMIZATION ANALYSIS	21
A. USER INPUT CONSIDERATIONS	21
B. DATA DERIVATION	24
1. Derivation of $REQTIME_{s,t}$	24
2. Derivation of $OK_{s,d}$	24
3. Derivation of $LENGTH_s$	26
4. Derivation of $ZOK_{d,t}$	26

V. POST-OPTIMIZATION ANALYSIS	28
A. SHIP TO DOCK ASSIGNMENTS	28
B. DOCK LOADING	28
C. CAPACITY UTILIZATION	29
D. SHIP NON-ASSIGNMENTS	30
VI. DATA MANAGEMENT AND THE GAMS PROGRAM	31
A. USER INTERFACE CONSIDERATIONS	31
B. THE GENERAL ALGEBRAIC MODELING SYSTEM (GAMS) ...	31
1. The User and GAMS	32
2. Data Input	33
3. Error Checking	34
C. A NAVAL SHIPYARD DRYDOCK LOADING AND CAPACITY UTILIZATION PROGRAM	35
1. Menu Templates	35
2. Data Entry Screens	38
a. Time Frame	38
b. Dock Data Entry Screen	40
c. Maintenance Data Entry Screen	41
d. Ship Data Entry Screen	42
3. Other Data Management Options	43

VII. FINDINGS AND RECOMMENDATIONS	44
A. FINDINGS	44
B. RECOMMENDATIONS	47
 APPENDIX A	 48
 LIST OF REFERENCES	 55
 INITIAL DISTRIBUTION LIST	 56

LIST OF FIGURES

Figure 1: Ship Schedule Overlaps	14
Figure 2: Consecutive Overlap Opportunities	18
Figure 3: User-Program Interface	33
Figure 4: Opening Template	35
Figure 5: Main Menu Template	36
Figure 6: Data Base Management Template	37
Figure 7: Dock Data Entry Screen	40
Figure 8: Maintenance Data Entry Screen	41
Figure 9: Ship Data Entry Screen	42
Figure 10: Drydock Capacity Utilization	45

I. INTRODUCTION

A. THE NAVAL SHIPYARD

One of the Navy's most valuable assets for the maintenance of its fleet is the Naval Shipyard. The Naval Shipyard provides the Navy a permanent location for the performance of major industrial work and maintains prime waterfront space for the docking of the fleet's ships. However, the reality of tight budgetary constraints and continued defense spending cutbacks is clear. Numerous classes of ships have been or are going to be decommissioned from service and new construction programs are slowing. As the drawdown of the Navy's force structure occurs, the requirement for the type and number of Naval Shipyards will change dramatically.

Currently there are eight Naval Shipyards. They are Portsmouth, Norfolk, Charleston, Philadelphia, Puget Sound, Mare Island, Long Beach and Pearl Harbor. Although the services shipyards provide are invaluable, maintaining shipyards is an expensive venture. As the force structure changes in the coming years and as the Navy's budget declines, it is paramount that the requirements for Naval Shipyards are known so as not to maintain unnecessary facilities.

B. THESIS MOTIVATION: FUTURE SHIPYARD REQUIREMENTS

Although there are many limiting factors which determine the type and number of shipyards required to maintain the fleet, one of the most important is the Naval Shipyard drydock. The Assistant Secretary of the Navy (Financial Management) Robert C. McCormack, upon recommendation from the Shipyard Facilities and Management Working Group, highlighted the need for developing alternatives for satisfying Navy drydock requirements. He stated in a 13 November 1991 memo to various OPNAV codes that "the current inventory of drydocks has been retained to meet projected future workload. It is now apparent that as the fleet grows smaller, and as the Navy budget declines, the projected requirements for drydocks in Naval Shipyards will be reduced."¹ He further directed the formation of the Shipyard Drydock Requirements Working Group and stated that the group's goals were to develop alternatives to satisfy future drydock requirements, to determine current excess capacity based on planned force levels and associated workloads, and to determine breakpoints in drydock requirements by varying force levels (a breakpoint is a circumstance or set of circumstances which requires more drydock capacity significantly above the average capacity required over the planning period).

The methodology that the group developed was to hypothetically load the Naval Shipyards' drydocks over a ten year period and to study the changes in overall drydock capacity utilization as maintenance strategies, force structures and drydock utilization

¹Memorandum from The Assistant Secretary of the Navy (Financial Management), 13 November 1991. Subject: Shipyard Drydock Requirements

parameters were varied. To meet the stated goals, the working group needed approximately twenty-five drydock loading plans developed. The current method of developing drydock loading plans is a manual process and requires approximately one to two weeks per excursion. Additionally, the working group had only four weeks from the time the group was formed until the Assistant Secretary of the Navy required a briefing on their findings.

OP-431 was designated the working group leader and felt it was necessary to create an optimization process to develop drydock loading plans more quickly and independently than the current method allowed. Thus is the motivation for *A Naval Shipyard Optimal Drydock Loading and Capacity Utilization Model* developed in this thesis.

C. MODEL DESCRIPTION

A Naval Shipyard Optimal Drydock Loading and Capacity Utilization Model is an integer program coupled with a data management control program which supports the needs of the working group. Specifically, the model

- optimally loads the Naval Shipyard drydocks through a specified time frame maximizing overall drydock capacity utilization,
- allows the user to modify input parameters,
- provides loading solutions within minutes allowing for quick and easy what if analysis, and
- allows for easy user interface.

The model is implemented on an i386 based personal computer with a math co-processor. The integer program is formulated via the *General Algebraic Modeling System (GAMS)* [Ref. 1] programming language and solved with the ZOOM solver [Ref. 2]. All user interface from data management to optimization is controlled via the *Naval Shipyard Drydock Loading and Capacity Utilization Program* written in Microsoft QBasic.

II. MODEL FORMULATION

One of the primary goals of the working group was to determine the level of excess capacity that exists in the Naval Shipyards' drydocks. Therefore, the objective of the *Naval Shipyard Optimal Drydock Loading and Capacity Utilization Model* is to efficiently utilize drydock capacity by finding the mix of ship-to-dock assignments over the planning period that maximizes overall drydock capacity utilization. Drydock capacity utilization is the percentage of time a drydock is loaded.

The model must also enforce constraints which reflect the physical capabilities of the drydocks and the requirements of the ships using those drydocks.

A. CONSTRAINTS OF A DRYDOCK LOADING PLAN

The loading of ships into drydocks is constrained by

- ships' required maintenance schedules,
- drydock capabilities,
- drydock current loads, and
- drydock preventive maintenance.

Additionally, the working group needed a method to vary the order in which docks are loaded and to hypothetically remove a dock (or set of docks) during the planning period. Therefore, docks may be loaded with the same or differing preferences as well as made hypothetically unavailable. This is accomplished by modifying the model's objective function but in such a way that maximum capacity utilization is still obtained.

1. Ship Schedules

At the start of each scheduling cycle, ship docking periods are fixed and known. Ships have a fixed start date that they must enter into a drydock and must remain in the drydock for a fixed amount of time to accomplish their required maintenance. Additionally, each ship's docking period is identified by a specific maintenance type. For example, if a SSN688 class submarine is entering into a drydock, the type of maintenance it requires may be a docking maintenance period (DMP) or a refueling overhaul (RFOH).

Although start and end dates of ship docking periods are planned to the day, for the purposes of this model, they will be indicated by the month only. Therefore, those dates which occur on the fifteenth or earlier of a month are scheduled in that month and those dates which occur after the fifteenth are scheduled for the next month. As stated, the working group's methodology was to hypothetically load the Naval Shipyards' drydocks over a ten year period. Indexing on the day of the month, versus the month only, would tend to make the model intractable.

2. Dock Capabilities

Docks differ in their capabilities. Not all docks are capable of performing all required ship dockings. For example, although a dock may be physically capable of docking a SSN688 class submarine, it may not have the proper equipment to perform a SSN688 class submarine refueling overhaul. Therefore, assignment of ships into drydocks depends upon the ship type, its required maintenance and the capabilities of the drydocks.

Dock capabilities may increase during the scheduling cycle. At the beginning of the scheduling cycle, a dock may not have the proper equipment to perform certain maintenance types but may be equipped to perform these maintenance types later in the scheduling cycle.

3. Current Load

At the beginning of each scheduling cycle, there may be docks which are physically occupied with ships from the previous planning period. These docks are unavailable for new business until the completion of those docking periods.

4. Drydock Maintenance

Normally, ten out of twelve months are available for ship dockings. The remaining two months are set aside for drydock preventive maintenance.

A technical discussion follows in which the model's indices, parameters and variables are presented as a prelude to the mathematical formulation.

B. INDICES

- **s** The set of ships requiring a Naval Shipyard drydock. If a ship requires more than one docking during the planning period, it is listed with a different name for each required docking.
- **d** The set of Naval Shipyard drydocks.
- **t** Time periods in YYMM format.

C. PARAMETERS

- $OPEN_{d,t}$ Equals one if dock d is open for new business in time period t , and is zero otherwise.
- $OK_{s,d}$ Equals one if dock d is capable of performing ship s 's docking period, and is zero otherwise. This parameter is derived for each ship and dock, depending on the dock's capability and availability and on the type and timing of the ship's required maintenance.
- $REQTIME_{s,t}$ Equals one if ship s must be in a dock during time period t , and is zero otherwise.
- $LENGTH_s$ Length, in months, of a ship's docking period.
- $PREF_d$ Preference of assigning ships to dock d . For example, if a ship can be assigned to two docks, the dock with the higher preference will load the ship.
- $PREF_{spill}$ Penalty (a negative value) for not assigning a ship to a Naval Shipyard drydock.

D. VARIABLES

- $X_{s,d}$ Binary assignment variable of ships to Naval Shipyard drydocks. Equals one if ship s is assigned to dock d , and is zero otherwise.
- $SPILL_s$ An elastic variable which equals one if ship s cannot be assigned to a drydock.

E. FORMULATION

Find $X_{s,d}$ and $SPILL_s$ to maximize

$$\sum_s \sum_d X_{s,d} \text{ PEF}_d \text{ LENGTH}_s + \sum_s SPILL_s \text{ PEF}_{spill} \text{ LENGTH}_s$$

Subject to:

$$(1) \sum_s X_{s,d} \text{ OK}_{s,d} \text{ REQTIME}_{s,d} \leq \text{OPEN}_{d,t} \quad \text{for all } d, t$$

$$(2) \sum_d X_{s,d} \text{ OK}_{s,d} + SPILL_s = 1 \quad \text{for all } s$$

$$(3) X_{s,d} = 0 \text{ or } 1 \quad \text{for all } s, d$$

$$(4) SPILL_s \geq 0 \quad \text{for all } s$$

1. Objective Function

The goal of the objective function is to maximize the overall capacity utilization of the Naval Shipyard drydocks while satisfying the preference for loading individual docks. Docks with the largest PEF_d are loaded with the highest priority, if feasible, but capacity utilization is still maximized if PEF_{spill} is sufficiently negative.

Inevitably, there are schedule conflicts between ships' required docking periods. For example, if two ships are competing for assignment to the last available drydock capable of performing their required maintenance type and their schedules overlap, the ship with the longer docking period is assigned to the dock. The other

ship's elastic variable $SPILL_s$ is set to one, which indicates this ship is not assigned to a Naval Shipyard drydock. The preference parameter $PREF_{spill}$ controls this assignment. Setting $PREF_{spill}$ sufficiently lower than $PREF_d$ for all docks ensures ship non-assignment occurs only as a last resort as capacity utilization is maximized.

The parameter $PREF_d$ in the objective function also enables the model to be used for finding optimal solutions in hypothetical situations when a dock (or a set of docks) is closed during the scheduling cycle. Setting $PREF_d$ lower than $PREF_{spill}$ ensures zero capacity utilization for those docks not to be loaded. By making a set of docks hypothetically unavailable, their impact on the loading of ships into drydocks is immediately apparent. Decreasing available drydock space will increase utilization of the remaining docks and it will probably increase the number of ships that cannot be assigned to any drydock. If the increase in unassigned ships resulting from the removal of a particular drydock (or set of drydocks) is small, then that drydock (or set of drydocks) has little impact on the Navy's maintenance capability.

2. Dock Loading Limitations

Constraint (1) simultaneously enforces four important restrictions:

- At most one ship at a time is allowed in any dock.
- At the start of the current planning period, some docks may be occupied with ships that commenced service earlier. These docks may not receive new ships for maintenance until their current work is finished. This aspect of the constraint is controlled by the $OPEN_{d,t}$ parameter.
- A ship will be assigned to a dock only if it is allowed there, as specified by the $OK_{s,d}$ parameter.

- When a ship is assigned to a dock, it must stay there during its entire required docking period.

In apparent conflict with the first restriction above, some Naval Shipyard drydocks are in fact capable of docking more than one ship at a time. The model accommodates these docks by splitting them into multiple docks. For example, if dock D1 is capable of holding two ships at a time, it is modeled as two docks, D1A and D1B.

As stated previously, one of the Navy's concerns about loading ships into drydocks is the requirement to perform maintenance on the drydocks themselves. Normally, ten months of a year are available for loading ships into drydocks, and two months are set aside for drydock maintenance. This policy cannot always be followed because there are ship docking periods which last over twelve months. It would be possible to explicitly model drydock maintenance, but an easier method for approximately handling this consideration was chosen instead. The method is to simply add a fraction of the required time off for drydock maintenance to each ship's docking period. This convention is reasonable because, normally, the shortest docking period over a scheduling cycle is four months. In rare instances where docking periods are only one or two months, addition of time off for drydock maintenance is not required.

For example, if a ship's docking period historically lasts five months, then one additional month is added to its total docking period. Thus, if two ships, whose historical time in dock is five months, are loaded back to back into the same drydock, it appears that the drydock is loaded twelve months continuously. Ten of the months are

the actual ship dockings and the remaining two months are for dock maintenance. This convention closely mimics the actual schedulers of drydock maintenance.

3. Ship Assignment

Constraint (2) ensures that each ship is assigned to at most one drydock. If ship s is not assigned to a Naval Shipyard drydock, then $SPILL_s = 1$.

III. MODEL ENHANCEMENT: RESOLVING SCHEDULE CONFLICTS

The model of the preceding chapter was implemented and numerous excursions were performed for the Shipyard Drydock Requirements Working Group. After each excursion was run, the list of ships not assigned to a drydock was examined carefully. It was found that in some cases, the schedule conflicts that caused some of the ships to be unassigned could be resolved by minor modification of the input data. This procedure for resolving schedule conflicts was a manual process that required a large amount of time and in-depth knowledge and experience with the model itself. Therefore, a method was needed to automate the conflict resolution.

A. RELAXATION OF LOADING CONSTRAINT

As stated in the previous chapter, if there are two ships competing for assignment to the last available drydock capable of performing their required maintenance types and their schedules overlap, the ship with the longer docking period is assigned to the dock and the other ship is unassigned. In reality, the schedule overlap may be as small as one month, in which case it may be reasonable to assign both ships to the same dock. (This assumes the dock is free for the rest of both ships' required docking periods.)

For example, assume ship S1's docking period starts in T4 and ends in T7 and ship S2's docking period starts in T7 and ends in T12. Also assume there is only one dock available for both ships and it is unloaded from T1 to T12. Under the current

formulation, ship S2 is assigned to the dock because it has the longer docking period.

Figure 1 illustrates the situation.

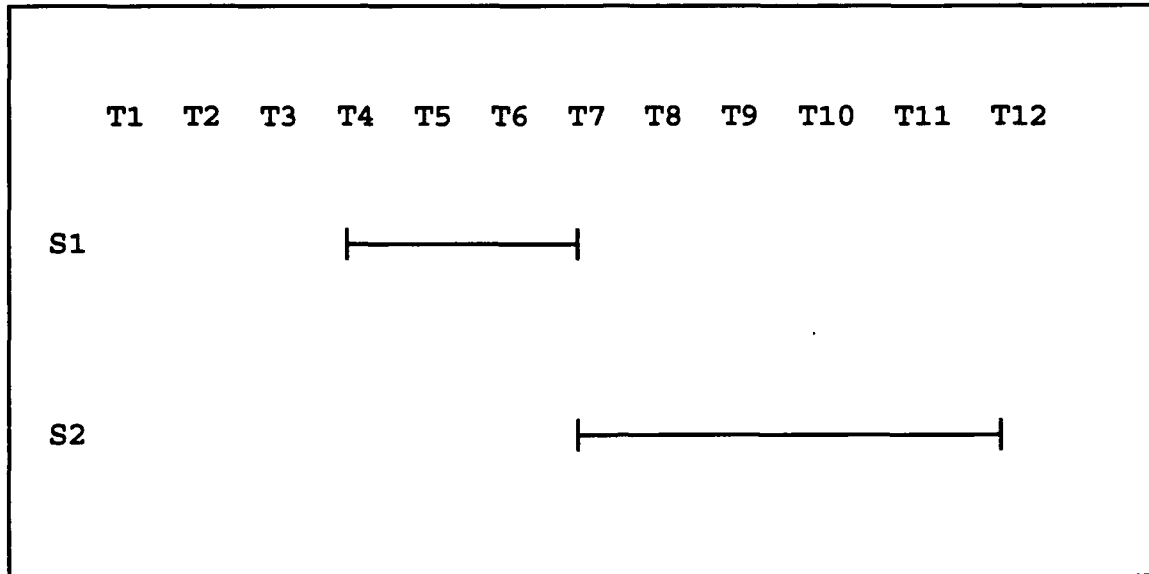


Figure 1: Ship Schedule Overlaps

The reality may be that ship S1's docking period ends at the beginning of T7 and ship S2's docking period begins at the end T7. In this case, it is more reasonable to assign both ships to the dock. If this assignment is allowed, capacity utilization increases further and reality is more effectively modeled.

The preceding example illustrates the need for an enhancement to the basic formulation. This enhancement allows one month overlaps to occur in docks as long as the overlap is at the end of one ship's docking period and the beginning of another ship's docking period.

B. OPTIMIZATION OPTIONS

Regardless of the reality of deliberately assigning one month overlaps, benefit can be obtained from the original formulation. Therefore, two optimization methods are available. The Rigid Optimization strictly adheres to the ship schedules where as the Flexible Optimization allows the one month overlaps to occur. By introducing new scalars, parameters and variables, one formulation can support both optimization options.

1. Additional Scalars

- **FLEX** Equals one if flexible option chosen for optimization, and is zero otherwise.
- **ZPEN_t** Penalty for an overlap assignment in time period t . The penalty for such assignment decreases as the time period occurs later in the scheduling cycle.

2. Additional Parameters

- **ZOK_{d,t}** Equals one if an overlap opportunity exists at dock d in time period t , and is zero otherwise.

3. Additional Variables

- **Z_{d,t}** Equals one if two ships are assigned to dock d in time period t as a result of a one month overlap in schedules, and is zero otherwise.

C. ENHANCED MODEL FORMULATION

Find $X_{s,d}$, $Z_{d,t}$ and $SPILL_s$ to maximize

$$\sum_s \sum_d X_{s,d} \text{PREF}_d \text{LENGTH}_s + \sum_s SPILL_s \text{PREF}_{spill} \text{LENGTH}_s \\ - \sum_d \sum_t Z_{d,t} \text{ZPEN}_t \text{FLEX}$$

Subject to:

$$(1) \sum_s X_{s,d} \text{OK}_{s,d} \text{REQTIME}_{s,t} \leq \text{OPEN}_{d,t} + Z_{d,t} \text{ZOK}_{d,t} \text{FLEX} \quad \text{for all } d, t$$

$$(2) \sum_d X_{s,d} \text{OK}_{s,d} + SPILL_s = 1 \quad \text{for all } s$$

$$(3) Z_{d,t} + Z_{d,t+1} \leq 1 \quad \text{for all } d, t \text{ if } \text{FLEX}=1$$

$$(4) X_{s,d} = 0 \text{ or } 1 \quad \text{for all } s, d$$

$$(5) Z_{d,t} = 0 \text{ or } 1 \quad \text{for all } d, t \text{ if } \text{FLEX}=1$$

$$(6) SPILL_s \geq 0 \quad \text{for all } s$$

1. Objective Function

The enhanced formulation relaxes some of the unnecessary restrictions imposed by discretizing the model by months. The new objective function tends to better maximize capacity utilization by allowing one month overlaps. The addition of the variable $Z_{d,t}$ and the parameter ZPEN_t accounts for overlap assignments. If such an assignment occurs, the objective function value is higher than if the overlap was not

allowed. This assignment occurs at a penalty but the penalty is less than if a ship is not assigned to a drydock. Therefore, overlap assignments will typically occur as a last resort.

2. Dock Loading Limitations

The four purposes of this constraint remain unchanged with the exception of allowing two ships in one dock if an overlap opportunity is taken. Because the scalar FLEX is multiplied by the decision variable $Z_{d,t}$ and the parameter $ZOK_{d,t}$, this assignment only occurs when the flexible option is chosen. If FLEX equals zero, the constraint of one ship per dock per time period is maintained regardless of overlap opportunities.

3. Ship Assignment

Constraint (2) remains unchanged from the rigid optimization formulation of Chapter II.

4. Non-consecutive Overlaps

In developing the enhanced formulation, it first appeared that the reformulation of dock loading limitations constraint (1) and the objective function was all that was needed to automate the scheduling of one month overlaps. However, when the model was optimized for certain instances of the data, an interesting unforeseen error occurred: a two month overlap between two ships at the same dock. This problem is best described graphically. Consider four ships, S1 through S4, whose maintenance schedules are depicted in Figure 2. For this example, it suffices to assume only one

drydock, d , in the problem. The four ships are competing for drydock d over a seven month period.

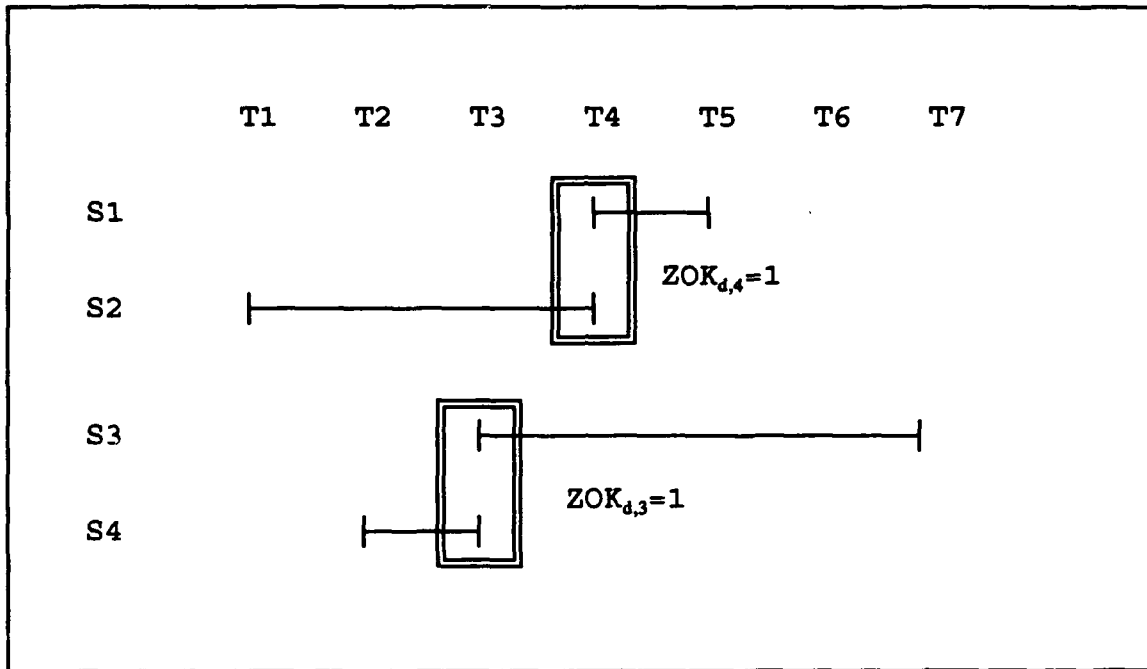


Figure 2: Consecutive Overlap Opportunities

The optimal loading plan, under the flexible optimization option, is to load ships S3 and S4 with a one-month overlap, and to let ships S1 and S2 go unassigned. The dock is then utilized for six out of seven months. The corresponding optimal values of the variables are

$$\begin{aligned}
 X_{1,d} &= X_{2,d} = 0 && \text{[Don't assign ships S1 and S2.],} \\
 X_{3,d} &= X_{4,d} = 1 && \text{[Assign ships S3 and S4.],} \\
 Z_{d,4} &= 0 && \text{[Don't use the S1-S2 overlap option in period 4.],} \\
 Z_{d,3} &= 1 && \text{[Use the S3-S4 overlap option in period 3.].}
 \end{aligned}$$

Unexpectedly, the results of the model consisting of constraints (1)-(2) and (4)-(6) were

$$X_{1,d} = X_{4,d} = 0,$$

$$X_{2,d} = X_{3,d} = 1,$$

$$Z_{d,3} = Z_{d,4} = 1.$$

By loading ships S2 and S3, this solution gives a better objective function value than the optimal solution above: it keeps the dock fully utilized. However, this solution is infeasible in reality because of the two month overlaps in periods T3 and T4. The model had to be in error if this real-world infeasible solution was mathematically feasible.

The cause of the error is that, in the model consisting of constraints (1)-(2) and (4)-(6), the X variables are not logically coordinated with the Z variables. For example, variable $Z_{d,3}$ corresponds to the option of overlapping ships S1 and S2 in period T3. But in the incorrect model, this variable was switched on even though ship S1 was not loaded. In other words, it is logically inconsistent to have $Z_{d,4} = 1$ and $X_{1,d} = 0$ in the same solution.

The first apparent method for correcting this modeling flaw was to redefine the overlap variable with four subscripts:

$Z_{d,t,s,s'}$ equals one if dock d in period t is allowed a one-month overlap consisting of ship s and s', and is zero otherwise.

With these variables, it is possible to formulate constraints that ensure the correct logical coordination between the X and Z variables. However, with over 150 ships to consider

in a typical model run, the large number of these four-dimensional integer variables would probably make the model intractable.

Fortunately, a much simpler correction of the error emerged. It is based on the following observation: the only way an error like the one above can happen is if the same dock is scheduled for overlaps in consecutive time periods (e.g., T3 and T4 in the example). Constraint (3) prevents consecutive overlaps and does so without increasing the dimensionality of the Z variables.

As a result, the model consisting of constraints (1)-(6) is a valid representation of the intended flexible optimization option. It yields real-world-feasible, optimal solutions with no limiting assumptions.

IV. PRE-OPTIMIZATION ANALYSIS

A. USER INPUT CONSIDERATIONS

As stated, one of the primary design criteria in the model is to allow for easy user interface. An effective method to ensure easy user interface is to derive the data required by the optimization program from minimal input. Thus, the *Naval Shipyard Drydock Loading and Capacity Utilization Program* was developed. This program elicits all user input, formats it and then passes control to the optimization program in which pre-optimization analysis occurs. The data management control program provides the following information for the pre-optimization analysis:

- Time frame (YYMM format)
Example: (9201, 9202, 9203, 9204, ...)
- Hull names
Example: (SSN688, SSN689, CV66, CGN38, ...)
- Dock names
Example: (D1, D2, D3A, D3B, ...)
- Maintenance types
Example: (688RFOH, 688DMP, CVDSRA, CGNCOH, ...)

The following data tables are also provided for pre-optimization analysis:

- Ship data: (HULLDATA_{s,m,"start"} and HULLDATA_{s,m,"end"})

Includes the ship name, the maintenance required, the start and end date of the ship's docking period.

Example:

<u>NAME(s)</u>	<u>MAINTENANCE(m)</u>	<u>START</u>	<u>END</u>
SSN690	688RFOH	9301	9307
CV66	CVDSRA	9410	9503

- Dock data: (OPEN_{d,i})

Includes the dock name and the date the dock is open for new business.

Example:

<u>NAME</u>	<u>DATE OPEN</u>
D1	9301
D2	9405

- Maintenance data: (MAINTDATA_{m,d,"early"})

Includes the maintenance name, the earliest date a dock is capable of performing that maintenance. If not included in the file, then the maintenance type and docks are incompatible.

Example:

<u>MAINTENANCE(m)</u>	<u>DOCK(d)</u>	<u>EARLY</u>
688RFOH	D1	9301
688RFOH	D2	9301
688RFOH	D3A	9504
688DMP	D1	9301
688DMP	D2	9301
CVDSRA	D3B	9301

Other data provided by the data management control program not used in the pre-optimization analysis follows:

- Dock loading preference: ($PREF_d$ and $PREF_{spill}$)

Includes the dock and its preference of loading.
Also includes the penalty for not assigning a ship to a dock.

Example:

<u>NAME</u>	<u>PREFERENCE OF LOADING</u>
D1	3
D2	2
D3	4
SPILL	-1

- Optimization option: (FLEX)

Includes the value of FLEX. If $FLEX = 1$ then the flexible option chosen. If $FLEX = 0$ then rigid option chosen.

B. DATA DERIVATION

Chapter II, section C and chapter III, section B, listed the parameters for the formulation. Of those parameters, only $OPEN_{d,t}$, $PREF_d$, $PREF_{spill}$ and $FLEX$ are useable in their original form. All other parameters are derived from the information provided by the user. Data derivation is implemented in the GAMS code using the following procedures.

To perform the data derivation, another index is required which is not part of the formulation. This index is m which represents the maintenance types.

1. Derivation of $REQTIME_{s,t}$

To build the parameter $REQTIME_{s,t}$, the information contained in the ship data table is used. Mathematically,

for all s ,

for m required by s ,

for all t ,

if $HULLDATA_{s,m,"start"} \leq t \leq HULLDATA_{s,m,"end"}$,

$REQTIME_{s,t} = 1$.

2. Derivation of $OK_{s,d}$

The parameter representing ship-to-dock compatibility, $OK_{s,d}$, clearly illustrates the benefit of automatic data derivation via GAMS. The values of $OK_{s,d}$ can be manually entered by the user, but for large numbers of ships, the process is tedious and error prone. Ship-to-dock compatibility depends on:

- ship's maintenance type,
- dock's capability as regards the ship type and its required maintenance type,
- ship's start date,
- the date the dock is open for new business, and
- the date the dock can start performing the ship's maintenance type.

This is implemented mathematically as

for all s and d ,

for m required by s ,

for all t ,

if $\text{MAINTDATA}_{m,d,"early"} > 0$

{the dock is physically capable of performing the ship's required maintenance m }

and $\text{PREF}_d > 0$

{the dock is to be loaded}

and $\text{MAINTDATA}_{m,d,"early"} \leq \text{HULLDATA}_{s,m,"start"}$

{the ship's docking period does not start before the earliest date dock d can start performing the required maintenance type}

and $\text{HULLDATA}_{s,m,"start"} \geq \text{OPEN}_{d,t} * t$,

{the ship's docking period does not start before the dock is open for new business}

then

$\text{OK}_{s,d} = 1$.

3. Derivation of $LENGTH_s$

The parameter $LENGTH_s$ is derived by subtracting the ship's end date from its start date and adding one. Mathematically,

for all s ,

$$LENGTH_s = HULLDATA_{s,m,"end"} - HULLDATA_{s,m,"start"} + 1.$$

4. Derivation of $ZOK_{d,t}$

Parameter $ZOK_{d,t}$ again illustrates the benefit of deriving data from user input. This parameter is needed to determine when one-month overlap opportunities exist. Manually determining all the possible opportunities over all docks and time periods is nearly impossible for a user.

The derivation is divided in two parts. First, it looks for overlaps which can occur with currently loaded ships. Mathematically,

for all s and d ,

for m required by s ,

$$\text{if } MAINTDATA_{m,d,"early"} > 0$$

{ d is capable of performing ship's docking period but is currently loaded}

and there exists a t such that

$$t = HULLDATA_{s,m,"start"}$$

$$OPEN_{d,t} = 0$$

$$OPEN_{d,t+1} = 1$$

{ t equals the ship's start date and is the last month of a currently loaded ship in dock d }

then

$$OK_{s,d} = 1$$

$$ZOK_{d,t} = 1.$$

Second, the derivation looks for overlap opportunities between pairs of ships in the scheduling cycle. Mathematically,

for all s and s' such that $s \neq s'$

for m required by s and m' required by s' ,

if there exists d and t such that

$$OK_{s,d} = 1$$

$$OK_{s',d} = 1$$

$$t = HULLDATA_{s,m,"start"}$$

$$t = HULLDATA_{s',m',"end"}$$

{ s and s' are allowed in d and
their schedules overlap by one month}

then

$$ZOK_{d,t} = 1.$$

V. POST-OPTIMIZATION ANALYSIS

Post optimization analysis results are calculated for purposes of insight into the capacity utilization of drydocks. Output from the GAMS optimization program is used as input in developing the following reports.

A. SHIP TO DOCK ASSIGNMENTS

Ship to dock assignments are known from the optimization results because the decision variable $X_{s,d}$ equals one if ship s is assigned to dock d .

B. DOCK LOADING

An interesting report that can be generated from the optimization is a visual representation of the dock loading per month. Let parameter $DCKLOAD_{d,t}$ equal one if dock d has a ship loaded in time period t . The two possible inputs into this parameter are the ships which are currently loaded prior to the scheduling cycle and the ships which are loaded as a result of the optimization. Mathematically,

for all d, t and s

if

$$OPEN_{d,t} = 0$$

{a ship is currently loaded prior to the
scheduling cycle}

and

$$X_{s,d} * REQTIME_{s,t} = 1$$

{a ship is assigned to dock d and requires a dock during time period t}

then

$$DCKLOAD_{d,t} = 1$$

An illustration of the output follows.

	D1	D2	D3
9301	1		1
9302	1		1
9303	1	1	
9304	1	1	
9305		1	1
9306	1		1

This report resembles that produced by the manual process with the exception of not listing the ship hull number under the dock. However, as stated in section A of this chapter, a report is generated listing ship to dock assignments.

C. CAPACITY UTILIZATION

Capacity utilization is determined per calendar year by summing all the months docks are loaded and dividing by the total number of dock months available. Before presenting the algorithm for computing capacity utilization, a return to docks that are capable of performing multiple dockings is required. As discussed in Chapter II, section E.2, these docks are split into as many docks as the number of ships they can load.

These additional docks represent capabilities not normally utilized. For example, although a dock may be capable of docking two ships at a time, normally the number of multiple ship combinations allowed is small. Therefore, counting that additional dock space when determining capacity utilization leads to artificially low numbers. Thus, although a dock may be split into two separate docks, it will contribute only twelve dock months available per year as opposed to twenty-four.

Let parameter $CAPUTIL_{year}$ equal the percent capacity utilization of all drydocks per year. Let set D' indicate those docks which have positive preference of loading and are the primary dock for those docks which are split because of multiple capabilities. The equation for capacity utilization per year is

$$CAPUTIL_{year} = \frac{\sum_{t \in year} \sum_{d \in D'} DCKLOAD_{d,t}}{12 |D'|}$$

where $|D'|$ is the cardinality of set D' .

D. SHIP NON-ASSIGNMENTS

The last report generated is those ships not assigned to a Naval Shipyard drydock because of schedule conflicts. If the variable $SPILL_s = 1$ in the optimal solution, ship s is not assigned. No further computation is required.

VI. DATA MANAGEMENT AND THE GAMS PROGRAM

A. USER INTERFACE CONSIDERATIONS

As stated earlier, user interface is of prime concern. Chapter IV discussed minimizing the amount of required user input as a method to increase model usability. Regardless of the amount of user input required, the user needs a method with which to enter, view and modify the data as well as view and print the reports from the optimization program. Any method which eases this interface further increases model usability.

Discussion of user interface and data management will incorporate both the GAMS and data management programs.

B. THE GENERAL ALGEBRAIC MODELING SYSTEM (GAMS)

The formulation discussed in Chapter III is implemented via the *General Algebraic Modeling System (GAMS)* software. Appendix A is a listing of the GAMS program for this model. As illustrated in Chapter IV, section A, data derivation is possible from minimal user input. All sets, parameters, scalars and tables required for the data derivation are provided to the GAMS program using the \$INCLUDE option of the GAMS programming language. The \$INCLUDE statement writes a data file located outside of the GAMS program into the GAMS program. The following example illustrates the syntax:

```
SET S      ships requiring NSY drydocks
/
$INCLUDE HULLNAME
/;
```

The included data files (HULLNAME, in this example) are created via the *Naval Shipyard Drydock Loading and Capacity Utilization Program*.

Figure 3 illustrates the interface provided by the data management control program between the user and the GAMS program. The prime benefits for using a control program are

- easy user interface with the optimization program,
- further reduction of required user input, and
- error checking subroutines in the data management control program.

1. The User and GAMS

Recalling the discussion on the optimization options, the user has two choices: the Rigid Optimization and the Flexible Optimization. The scalar FLEX determines which option is in effect. When the user executes the optimization program from the data management control program, he or she simply answers a yes-or-no question as to which option will be in effect. The data management control program then builds the correct data file for inclusion into the GAMS program.

After optimization occurs, the reports section is generated utilizing the algorithms discussed in Chapter V. However, the reports are contained in the GAMS listing file which is a copy of the GAMS code and optimization statistics. Retrieving the

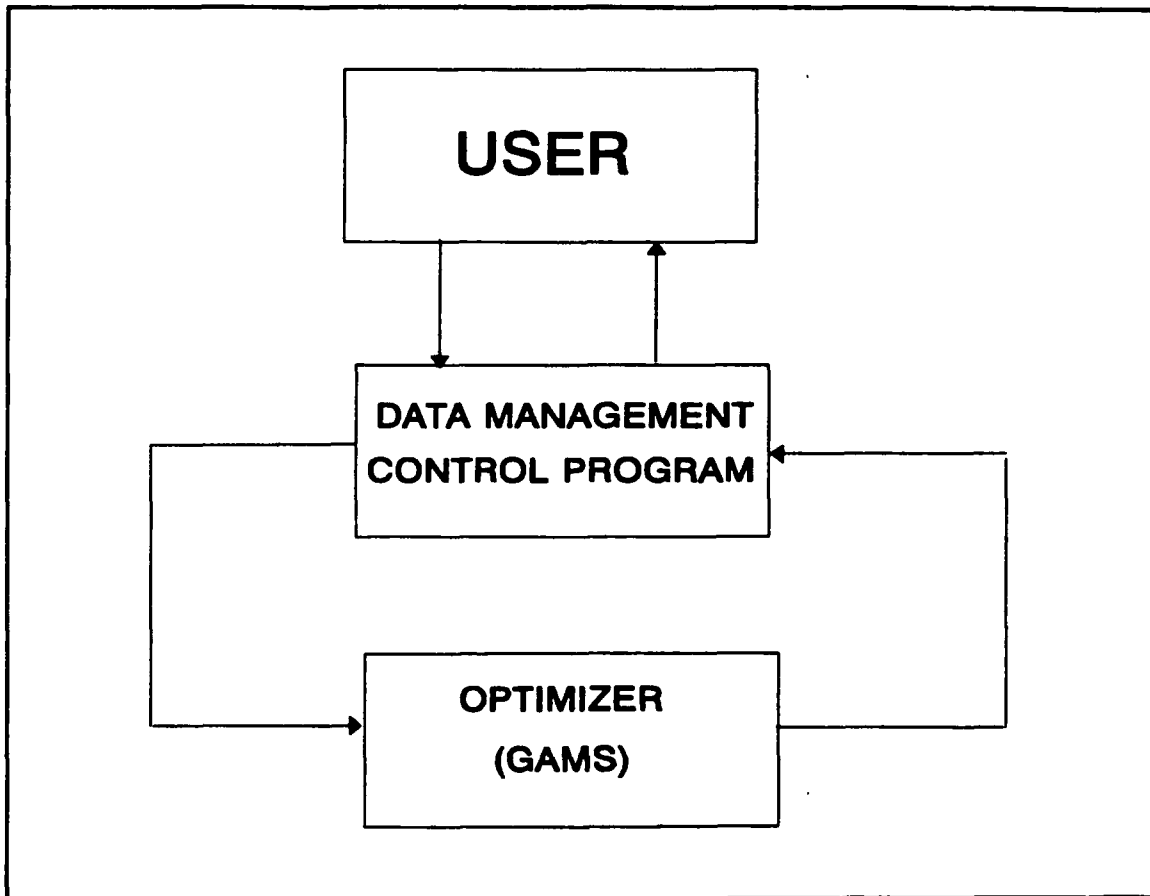


Figure 3: User-Program Interface

reports from the listing file is cumbersome. Because the listing file is formatted in a predetermined way, the data management control program can easily extract the required reports for the user.

2. Data Input

As stated, a prime benefit of controlling user interface via a data management control program is that required user input is further reduced. For example, the GAMS software requires that all elements of a set be listed. Recalling the set T, the time

periods of the scheduling cycle, illustrates this point well. The set T would include 96 entries for a scheduling cycle covering 1993 to 2000. If a user had to input this set manually, accounting for all keystrokes associated with the set elements and syntax requirements, he would have to hit 481 keys. Utilizing the data management control program, the user is required to hit only 6 keys. Additionally, the data management control program also checks the entries for errors. For example, it ensures the last year of the scheduling cycle is not before the first year of the scheduling cycle.

3. Error Checking

The preceding example illustrates the benefits of error checking, but the need for this option cannot be overemphasized. A GAMS set can never have two elements that are the same. (This is for the user's protection. The software cannot distinguish between the user mistakenly using the same name for different objects and the user re-entering an old object with new data.) The number of ships, docks, maintenance types and months in the scheduling cycle are numerous, so duplicate set elements may occur if the data is entered manually. However, all required input is obtained via the data management control program which checks for duplication and other errors. It is more convenient for the user if these errors are detected before, rather than after, GAMS is invoked.

C. A NAVAL SHIPYARD DRYDOCK LOADING AND CAPACITY UTILIZATION PROGRAM

1. Menu Templates

A Naval Shipyard Drydock Loading and Capacity Utilization Program is a hierarchical menu-driven system in which the user chooses various options from data management and manipulation, to optimization execution, to report listing and display. Figure 4 is the opening template of the program. As stated, the model was developed specifically for the Shipyard Drydock Requirements Working Group. One of the group's needs was to separate the east and west coast data bases. Therefore, when the program is executed, the first choice the user makes is the coast (east or west) in which to work.

**A NAVAL SHIPYARD DRYDOCK LOADING AND
CAPACITY UTILIZATION PROGRAM**

by
Lieutenant Richard A. Brown, USN
Operations Analysis Curriculum (Code 30)
Naval Postgraduate School
Monterey, California 93940

POC: Richard E. Rosenthal, PHD
Naval Postgraduate School
Tel: (C) (408) 646-2795

ENTER E FOR EAST COAST OR W FOR WEST COAST OPTIONS:

Version 1.0NUMS LOCK CAPS LOCK 20:18:03

Figure 4: Opening Template

Following this choice, the next menu template is the main menu. From this menu, the user can

- manage the data base,
- execute the optimization program,
- print or display the reports,
- change to the other coast, and
- exit the program.

Figure 5 is the main menu template.

NAVAL SHIPYARD DRYDOCK LOADING PROGRAM EAST COAST OPTIONS			
(D)	DATA BASE MANAGEMENT		
(X)	EXECUTE OPTIMIZATION PROGRAM		
(R)	REPORT PRINTING AND DISPLAY		
(C)	CHANGE TO OTHER COAST		
(ESC)	EXIT PROGRAM TO DOS		
Version 1.0		EAST NUMS LOCK CAPS LOCK	20:18:38

Figure 5: Main Menu Template

If the user chooses option (D) for Data Base Management, Figure 6 is the template presented on the screen. From this menu, the user can

- initialize the data base,
- make individual changes to the ship, dock or maintenance data bases,
- display the current data base,
- save or restore data bases, and
- escape to the main menu.

NAVAL SHIPYARD DRYDOCK LOADING PROGRAM DATA BASE MANAGEMENT			
(I)	INITIALIZE DATA BASE		
(M)	MAKE INDIVIDUAL CHANGES		
(D)	DISPLAY CURRENT DATA		
(S)	SAVE CURRENT DATA BASE		
(O)	RESTORE AN OLD DATA BASE		
(ESC)	ESCAPE TO MAIN MENU		
Version 1.0		EAST NUMS LOCK CAPS LOCK	20:19:11

Figure 6: Data Base Management Template

While working in the program, the user always knows which data base is current because of the coast indication field at the bottom of the template. Notice in Figure 5 and Figure 6 the word EAST at the bottom of the template. As the user makes choices via the menu templates, either an additional template is presented for him to make more choices, or a data entry screen is presented for data input.

2. Data Entry Screens

When a user initializes the data base, option (I) in Figure 6, he is now entering data into the data base. The data entry screens are the method by which a user's input is minimized. The data base management program takes the user's input, checks for errors, and then formats the input into the required sets, parameters, scalars and tables for use by the GAMS program. These formatted files are either used directly in the formulation or in pre-optimization analysis. The input required via the data entry screens are

- time frame,
- dock data,
- maintenance data, and
- ship data.

a. Time Frame

The user must input the last two numbers of the beginning year of the scheduling cycle and the ending year of the scheduling cycle. For example, if the first

year of the scheduling cycle is 1993 and last year of the scheduling cycle is 2000, the data entry screen, after all entries are made, is

ENTER FIRST YEAR TO LOAD DOCKS: 93

ENTER LAST YEAR TO LOAD DOCKS: 00

The program then builds the set T which is in YYMM format. The program also builds another data file which is used extensively throughout the program. This data file lists the time period t and its corresponding position in the scheduling cycle. For example, time period 9308 is the eighth month of the scheduling cycle as time period 9402 is the fourteenth month of the scheduling cycle. The GAMS software can take advantage of the ordinal nature of time scales to simplify the coding of the formulation as well as the pre-optimization analysis.

Recalling that the parameter $OPEN_{d,t}$ equals one if dock d is open in time period t illustrates the use of the ordinal nature of time scales. Because GAMS can distinguish between the relative position of elements of a set with the function ORD(), the subscript t is dropped from $OPEN_{d,t}$. $OPEN_d$'s meaning also changes. It now represents the month of the scheduling cycle that dock d is open for new business. However, its purpose in the formulation has not changed, just the manner in which it is incorporated in the GAMS formulation is slightly different. The capability to list open, start and end dates via the above convention makes the pre-optimization analysis in GAMS possible because the program easily distinguishes between relative locations in the set T.

b. Dock Data Entry Screen

Figure 7 is the dock data entry screen. The user inputs the dock name, the date the dock is open for new business and indicates whether this dock is the primary dock for a dock which can hold multiple ships. After all docks are entered, the program then builds the data files used for the set of docks, D , the set of docks over which the capacity utilization is to be computed, $\text{PRIMDCK}(D)$, and the parameter OPEN_d .

DOCK RECORD # 1

DOCK NAME:

DATE OPEN FOR NEW BUSINESS:

PRIMARY DOCK? (Y/N)

Figure 7: Dock Data Entry Screen

The program then prompts the user for the manner he would like the docks loaded: same preference of loading or different preference of loading. If the user chooses to load with different preferences, an information screen instructs the user how to tag docks which are not to be loaded or how to vary their loading preferences. After this phase, the program builds the data file used for the parameter PREF_d .

c. Maintenance Data Entry Screen

Figure 8 is the maintenance data entry screen. The user inputs the maintenance type and then indicates the date each individual dock can begin performing this maintenance type. If the dock is unable to perform this maintenance type, then its entry field is left blank. After all maintenance types are entered, the program builds the first data file used for the pre-optimization analysis of ship-to-dock compatibility. Specifically, data table $\text{MAINTDAT}_{m,d,\text{"early"}}$ is created, again using the ordinal nature of the time scale.

MAINTENANCE RECORD # 1	
MAINTENANCE TYPE IDENTIFIER:	
Enter earliest date (YYMM) indicated dock can perform this maintenance type. Leave blank if dock unable to perform maintenance.	
D1----->	
D2----->	
D3A----->	
D3B----->	
D4----->	
D5----->	

Figure 8: Maintenance Data Entry Screen

The program also builds the data file used for the set of maintenance types, m . Although this index is not part of the mathematical formulation contained in Chapter III, it is required in the GAMS pre-optimization portion of the program.

d. Ship Data Entry Screen

Figure 9 is the ship data entry screen. The user inputs the ship name, its required maintenance type, the start date of its docking period and how long (in months) it is required to be in a dock. The program then builds the data files used for the set of ships, S , and the table $HULLDATA_{i,m}$, where the $*$ indicates two dates. The first date is the ordinal month of the scheduling cycle in which the ship starts its docking period and the second date is the ordinal month in which the ship ends its docking period. These dates are computed from the user's input.

SHIP DATA RECORD # 1	
SHIP NAME:	MAINTENANCE TYPE:
START DATE (YYMM):	
LENGTH (MONTHS) :	

Figure 9: Ship Data Entry Screen

3. Other Data Management Options

After a data base is initialized, the user can modify various parts of the data base. The data entry screens are similar and, in some cases, identical to those of the initialization phase. Modifications the user can make are

- addition of docks,
- addition or deletion of ships,
- addition of maintenance types, and
- changes in preference of loading.

VII. FINDINGS AND RECOMMENDATIONS

A. FINDINGS

Prior to the development of this model, drydock loading plans have always been built manually. This is a time consuming procedure averaging one to two weeks. The Shipyard Drydock Requirements Working Group needed approximately twenty-five loading plans for its analysis. Given a time constraint of four weeks until the group was required to report back to the Assistant Secretary of the Navy, the manual procedure was unsatisfactory and the *Naval Shipyard Optimal Drydock Loading and Capacity Utilization Model* became a necessity. Within a three week period, the basic model was formulated and implemented, the data were collected and verified, and all required excursions were run. The excursions called for variation in

- maintenance strategies,
- force structures, and
- drydock utilizations.

Numerous excursions were performed in which the model developed optimal loading plans. Figure 10 represents overall drydock capacity utilization for three of those excursions. Three shipyards on the east coast were modeled over a nine year period. The shipyards are identified as A, B, and C. Their docks were optimally loaded with the CNO schedule of required ship dockings as it looked at the end of 1991. In the three excursions presented in Figure 10: (1) all docks were available, (2) the "C" shipyard

drydocks were hypothetically unavailable and (3) the "A" shipyard drydocks were hypothetically unavailable. Figure 10 represents solutions obtained with data available at the end of 1991 and is provided only to illustrate how an optimal loading plan with its associated capacity utilizations can indicate drydock loading breakpoints. Figure 10 does not represent solutions that would result with data that is currently available.

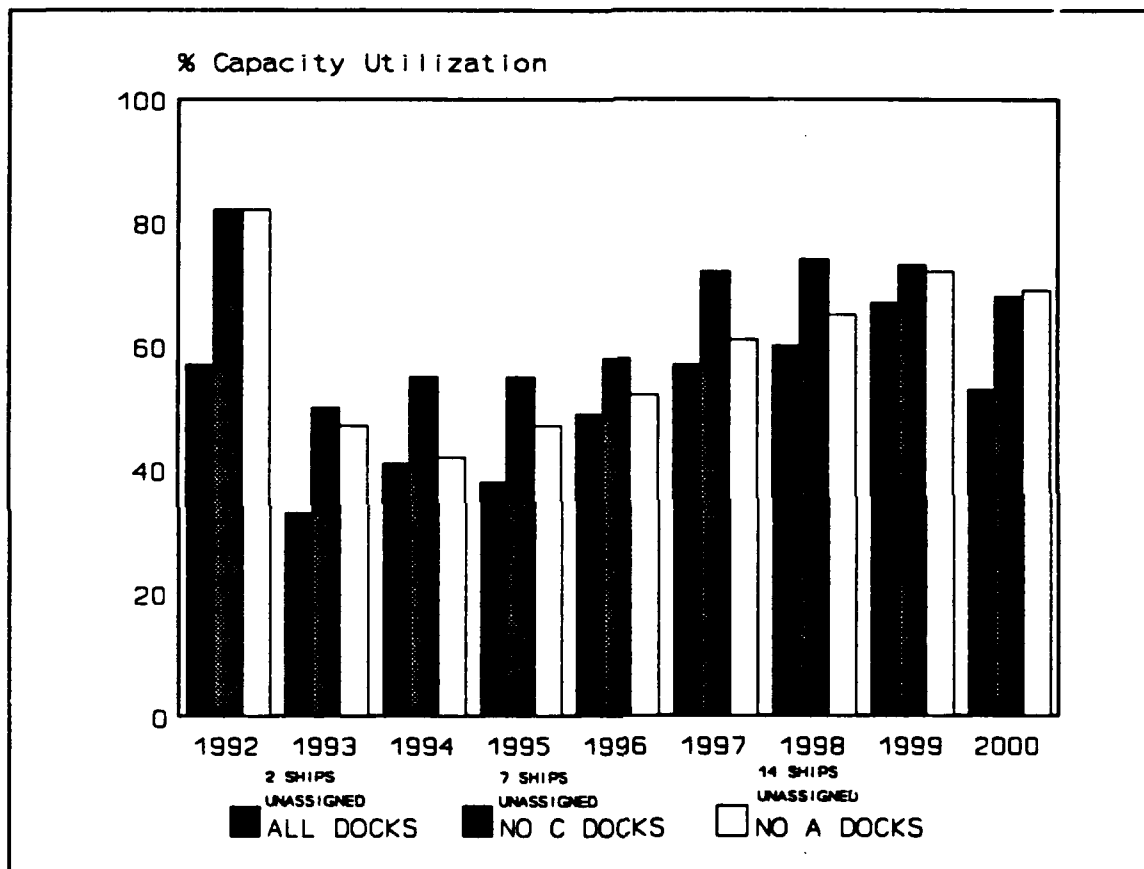


Figure 10: Drydock Capacity Utilization

The first excursion was a baseline developed using all docks. The highest capacity utilization obtained was approximately 70% in 1999 leading one to believe that there may be as much as 30% excess capacity in the Naval Shipyards' drydocks. Because of schedule conflicts, two ships were unassigned.

The second excursion made the "C" shipyard drydocks hypothetically unavailable. The resulting capacity utilization over all remaining drydocks increased significantly (upwards to 80%) per year. However, seven ships were unassigned. Although at first glance finding dock space for seven ships seems excessive, this averages out to one unassigned ship per year. The increase in capacity utilization and the small number of unassigned ships indicated that the "C" shipyard drydocks had little impact over the scheduling cycle on the loading of ships into drydocks .

The third excursion made the "A" shipyard drydocks hypothetically unavailable. As in the second excursion, the resulting capacity utilization over all remaining drydocks increased, but by a lesser amount. Additionally, the number of ships left unassigned doubled. This indicated that the "A" shipyard drydocks had a more significant impact over the scheduling cycle on the loading of ships into drydocks than did the "C" shipyard drydocks.

Regardless of the excursion, capacity utilization increased in the out years. Analysis of the data base showed that a certain class of ship was entering into a maintenance strategy that required more dock space than in the earlier years. Therefore, the working group developed additional loading plans in which the force structure and

maintenance strategy of this class of ship were varied. These loading plans clearly identified the requirements of this class of ship as a breakpoint in drydock loading.

The report of the Shipyard Drydock Requirements Working Group to the Assistant Secretary of the Navy (Financial Management) contains all of the assumptions, conclusions and recommendations that the study developed. As of the writing of this thesis, the report is in draft form.

From the Navy's standpoint, the bottom line is that the model accurately and effectively loaded the Naval Shipyard drydocks and was capable of modeling all excursions required from the working group. Moreover, it was developed quickly enough to provide answers while the questions were still being asked.

B. RECOMMENDATIONS

Although developed as a tool to study drydock capacity utilization, the model should be used to develop actual loading plans because it

- provides optimal loading solutions,
- lacks limiting assumptions, and
- provides solutions quickly.

With minor modifications, the issues of quality of life for ships' crews can be added into the model. For example, in an effort to minimize the distance ships are dislocated from their homeport during their docking periods, the objective function can be modified to penalize the assignment of ships to docks that are located far from the ships' homeports.

APPENDIX A

\$TITLE Naval Shipyard Drydock Loading Model

*

* **Programmer:** Lieutenant Richard A. Brown, USN

* **Advisor:** Richard E. Rosenthal, PhD

*

Department of Operations Research

*

Naval Postgraduate School

*

Monterey, Ca 93940-5000

*

Tel: (408) 646-2795

*

\$offupper offsymxref offsymlist offuellist inlinecom { }

options

limrow = 0

limcol = 0

solprint = off

optcr = .1

optca = 0

iterlim = 10000

reslim = 5000

integer1 = 1

integer2 = 122

;

SETS

S ships requiring NSY dock

/

\$include hllnamee

/

M maintenance type

/

\$include midene

/

D dock name

/

\$include dckdatae

/

PRIMDCK(D) docks not to include multiple capabilities

/

\$include primdcke

/

T time frame of scheduling cylce in YYMM format

/

\$include timdatae

/

YEAR years in scheduling cylce

/

\$include yrdatae

/;

TABLE HULLDATA(S,M,*) ship with its maintenance type start end date

\$include hlldatae

;

TABLE MAINTDAT(M,D,*) maintenance type capable docks earliest date

\$include mdatae

;

PARAMETER OPEN(D) time period dock is open for new business

/

\$include opndatae

/

;

PARAMETER PREF(*) preference of assigning ships to docks

/

\$include prfdatae

/;

SCALAR FLEX "1 if conflict allowed, 0 if not"

/

\$include flxdatae

/

ZPEN penalty for deliberate conflict / 3 / ;

ZPEN = ZPEN * FLEX ;

PARAMETER START(S) starting time for ship s maintenance

END(S) ending time for ship s maintenance ;

START(S) = SUM(M, HULLDATA(S,M,"START")) ;

END(S) = SUM(M, HULLDATA(S,M,"end")) ;

PARAMETER CAPABLE(S,D) compatible ship-dock assignments ;

CAPABLE(S,D) = 1 \$

- * the dock must be physically capable to perform maintenance
- * type m:

SUM(M, MAINTDAT(M,D,"EARLY") AND (PREF(D) gt 0)

AND

- * the ship must require maintenance type m and its start date
- * cannot be before the earliest date dock d can start
- * performing maintenance type m:

(MAINTDAT(M,D,"EARLY") LE HULLDATA(S,M,"START")) ;

PARAMETER OK(S,D) allowable ship-dock assignments ;

OK(S,D) = 1 \$ (

- * Dock must be capable of ship's required
- * maintenance type:

CAPABLE(S,D)

AND

- * Dock must not be busy with old work when ship
- * work scheduled to start:

(OPEN(D) le START(S))) ;

PARAMETER REQTIME(S,T) times when ship requires service ;

$$\text{REQTIME}(S,T) = 1 \text{ \$ ((ORD}(T) \text{ ge START}(S) \text{)}$$
$$\text{AND (ORD}(T) \text{ le END}(S) \text{)) ;}$$

PARAMETER LENGTH(S) length of ship s required maintenance ;

$$\text{LENGTH}(S) = \text{END}(S) - \text{START}(S) + 1 ;$$

SCALAR DCKMNTHS the number of dockmonths in one year ;

$$\text{DCKMNTHS} = \text{SUM}(\text{PRIMDCK}(D) \text{ \$ (PREF}(D) \text{ GT 0), 1) * 12 ;}$$

PARAMETER ZOK(D,T) times when dock conflicts are allowable ;

$$\text{ZOK}(D,T) = 0 ;$$

* First, look for opportunities to finish old work early. This
* is possible if there is some ship ready and able to start the
* month before the dock opens.

```
loop( (s,d) $ ( capable(s,d) and not ok(s,d) ),  
  loop( t,  
    if( ( ord(t) eq open(d) - 1 ) and  
      ( ord(t) eq start(s) ),  
      ok(s,d) $ flex = 1 ;  
      zok(d,t) = 1 ;  
    ) ; {endif}  
  ) ; {end t loop}  
); {end (s,d) loop}
```

* Second, look for opportunities to schedule the last month of one
* ship at the same time and dock as the first month of another
* ship.

ALIAS (S,SS) ;

```
loop( (s,ss) $ ( ord(s) ne ord(ss) ),  
  loop( t,  
    if( ( ord(t) eq start(s) ) and  
      ( ord(t) eq end(ss) ),  
      loop( d $ ( ok(s,d) * ok(ss,d) ),
```

```

        zok(d,t) = 1 ;
        overlap(s,ss,d,t) = yes ;
    ) ; {end d loop}
) ; {end if}
) ; {end t loop}
) ; {end (s,ss) loop}

```

BINARY VARIABLES

X(S,D) assignment of ships to Navy docks
SPILL(S) assignment of ships to non-Navy docks ;

POSITIVE VARIABLES

Z(D,T) deliberate assignment of conflicting ship to dock ;
Z.UP(D,T) \$ (FLEX * ZOK(D,T)) = 1 ;

FREE VARIABLE CAPACITY ;

- * The goal is to maximize the capacity utilization of
- * Naval Shipyard Drydocks and to minimize the non-assignment of
- * ships. The optimization can be performed with two options.
- * Option 1 (Rigid adherence to the schedule provided by
- * the user) and Option 2 (Flexible adherence to the schedule
- * provided by the user). Under Option 2, the optimization
- * allows for assignment of two ships, whose start date and
- * end date overlap by one month, to the same dock. This
- * assignment is secondary to assignment of the ships to
- * separate docks and only occurs as a last resort.

EQUATIONS

UTILIZE optimize capacity utilization of NSY drydocks

ONESHIPDCK(D,T) ensure only one ship per dock per month.
 * ensure only at most two ships per dock per
 * month under the Flexible option.

ZRESTRICT(D,T) cannot have two consecutive overlaps

ASSIGNDOCK(S) ensure a ship is assigned to a dock ;

UTILIZE..

*** Maximize Capacity Utilization:**

SUM((S,D)\$OK(S,D), X(S,D)*PREF(D)*LENGTH(S))

*** Less non-assignment:**

+ SUM(S, SPILL(S) * PREF("SPILL") * LENGTH(S))

*** less conflict penalties:**

- ZPEN * SUM((D,T) \$ ZOK(D,T), Z(D,T) * .999 ** ORD(T))

=E= CAPACITY ;

ONESHIPDCK(D,T) \$ (ORD(T) ge (OPEN(D) - FLEX))..

SUM(S\$(OK(S,D) AND REQTIME(S,T)), X(S,D))

=L= 1 + Z(D,T) \$ FLEX * ZOK(D,T) ;

ZRESTRICT(D,T) \$ (ZOK(D,T)*ZOK(D,T+1)) ..

Z(D,T) + Z(D,T+1) =L= 1 ;

ASSIGNDOCK(S).. SUM(D\$OK(S,D), X(S,D)) + SPILL(S) =E= 1 ;

MODEL DOCKS /ALL/ ;

SOLVE DOCKS USING MIP MAXIMIZING CAPACITY ;

**** REPORT GENERATION SECTION ****

PARAMETER DCKLOAD(T,*) one indicates dock loaded in month ;

DCKLOAD(T,D)\$(SUM(S,X.L(S,D)*REQTIME(S,T)) GE 1) = 1;

DCKLOAD(T,D)\$(ORD(T) LT OPEN (D))=1;

OPTION DCKLOAD:0:1:1;

DISPLAY DCKLOAD ;

PARAMETER NOTASSGN(S) ships not assigned to a dock ;

NOTASSGN(S)\$(SPILL.L(S))=1 ;
OPTION NOTASSGN:0:0:1;
DISPLAY NOTASSGN ;

PARAMETER CAPUTIL(*) percent loading in indicated year ;

CAPUTIL(YEAR)=(SUM((T,PRIMDCK(D))\$(ORD(T) GT (ORD(YEAR)-1)*12
AND ORD(T) LE ORD(YEAR)*12 AND PREF(D)),
DCKLOAD(T,D))/DCKMNTHS)*100 ;

OPTION CAPUTIL:2:0:1;
DISPLAY CAPUTIL ;

PARAMETER SHPTODCK(S,D) one indicates ship s assigned to dock d ;

SHPTODCK(S,D)\$(X.L(S,D) EQ 1) = 1;
OPTION SHPTODCK:0:1:1;
DISPLAY SHPTODCK;

LIST OF REFERENCES

1. Brooke, Kendrick, Meeraus, *GAMS, A User's Guide*, The Scientific Press, 1988
2. Marsten and Singhal, *ZOOM/XMP-386 Version 2.2*, XMP Optimization Software Inc., 1990

INITIAL DISTRIBUTION LIST

- | | | |
|----|---|---|
| 1. | Defense Technical Information Center
Cameron Station
Alexandria, Virginia 22304-6145 | 2 |
| 2. | Superintendent
Attn: Library, Code 1424
Naval Postgraduate School
Monterey, California 93940-5000 | 2 |
| 3. | Richard E. Rosenthal, PhD
Department of Operations Research
Naval Postgraduate School
Monterey, California 93940 | 4 |
| 4. | Eric S. Theise, PhD
Department of Operations Research
Naval Postgraduate School
Monterey, California 93940 | 1 |
| 5. | Lieutenant Richard A. Brown, USN
65 Fairmount Street
Lowell, Massachusetts 01852 | 2 |
| 6. | Chief of Naval Operations
OP-80
Navy Department
Washington, DC 20350 | 1 |
| 7. | Chief of Naval Operations
OP-801G
Navy Department
Washington, DC 20350 | 1 |
| 8. | Chief of Naval Operations
OP-81
Navy Department
Washington, DC 20350 | 1 |

- | | | |
|-----|---|---|
| 9. | Chief of Naval Operations
OP-431
Navy Department
Washington, DC 20350 | 1 |
| 10. | Chief of Naval Operations
OP-814
Navy Department
Washington, DC 20350 | 1 |
| 11. | Superintendent
United States Naval Academy
Annapolis, Maryland 21402 | 1 |
| 12. | Robert F. Dell, PhD
Department of Operations Research
Naval Postgraduate School
Monterey, California 93940 | 1 |